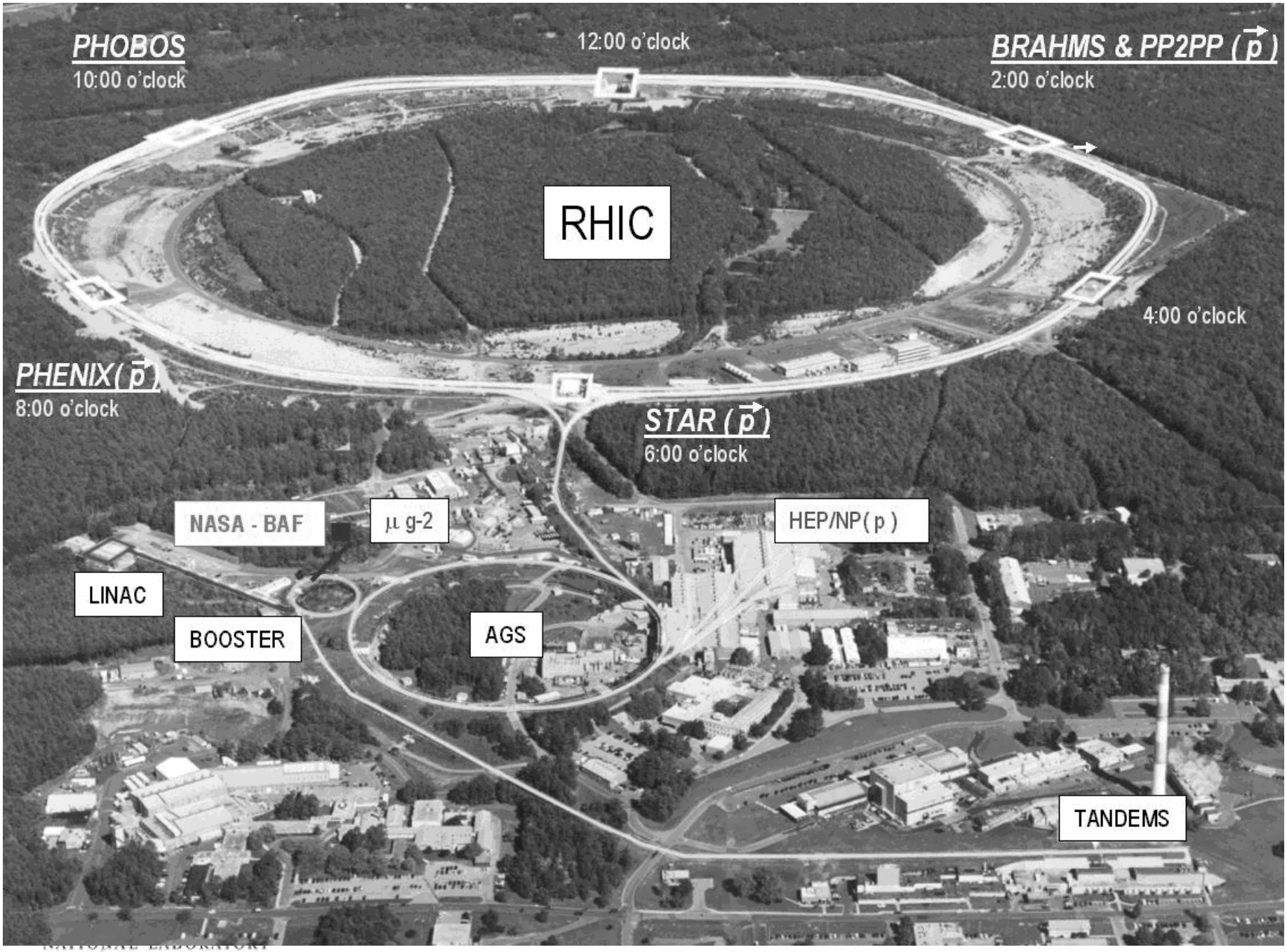
RHIC Status and Plans

RHIC is a very flexible collider:

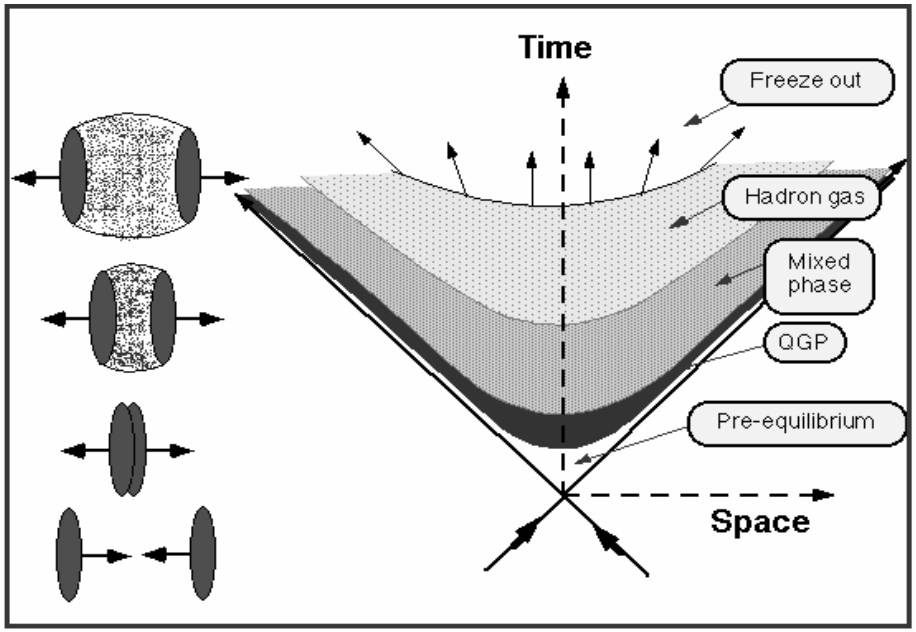
Au – Au collisions [RUN-2 (2001/2002)]
d – Au collisions [RUN-3 (2002/2003)]
Polarized proton collisions [RUN-2 and RUN-3]

RHIC luminosity upgrade plans


PHOBOS
10:00 o'clock
12:00 o'clock
BRAHMS & PP2PP ($\vec{p}$)
2:00 o'clock
RHIC
4:00 o'clock
PHENIX($\vec{p}$)
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
NASA - BAF
μ g-2
HEP/NP(p)
LINAC
BOOSTER
AGS
TANDEMS

A Mini-Bang:
Nuclear matter at extreme temperatures and density

Colliding gold at 100 + 100 GeV/nucleon (40 TeV total cm energy)



a. Formation phase -
parton scattering

b. Hot and dense phase -
quark-gluon plasma and hadron gas

c. Freeze-out –
emission of hadrons

Produce and explore a new state of matter-- quark-gluon plasma

Excite the QCD vacuum on a large scale

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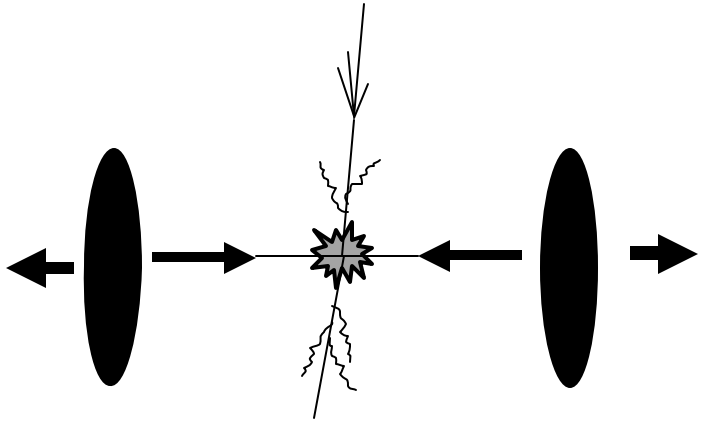
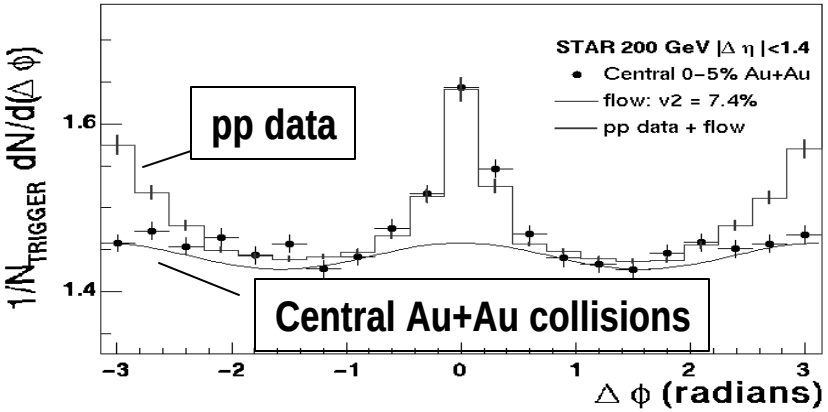
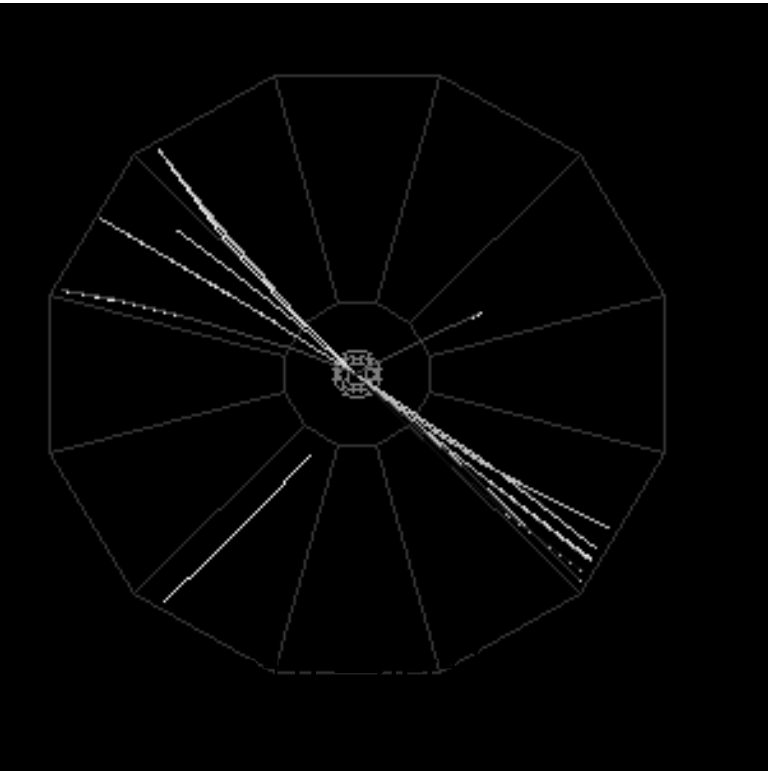
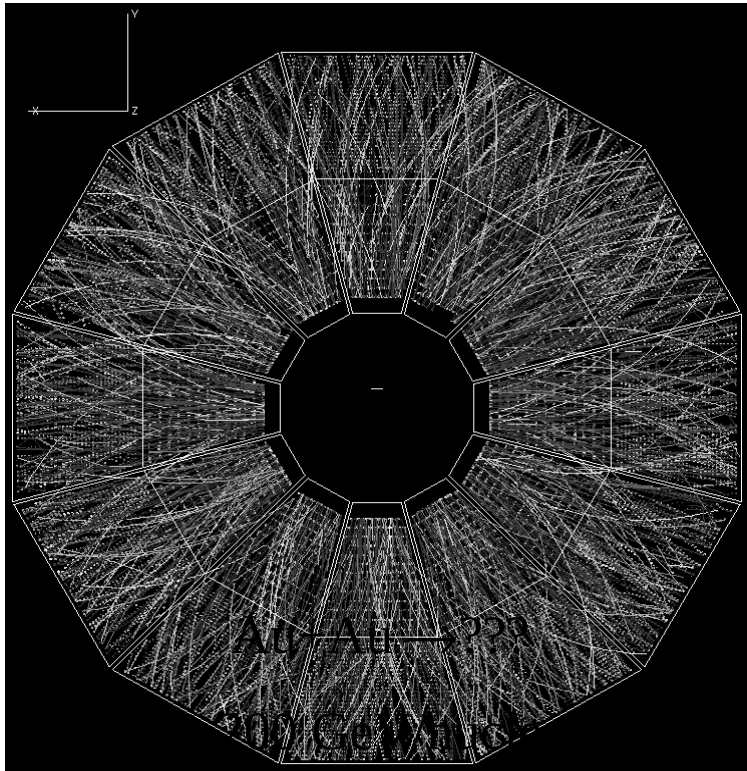
Hard Scattering at RHIC

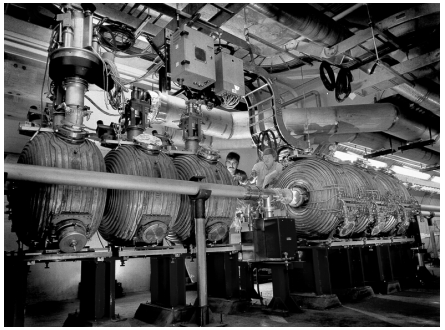


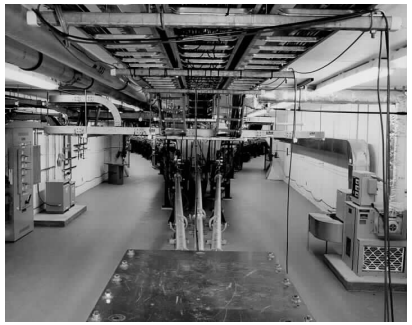


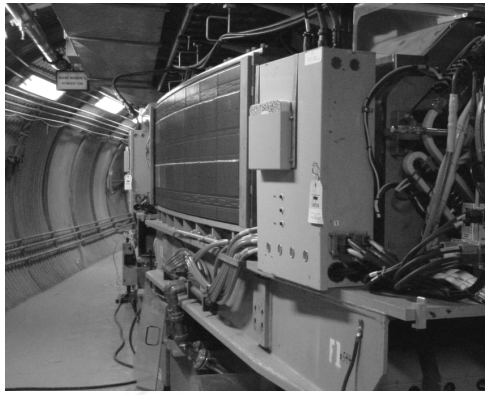




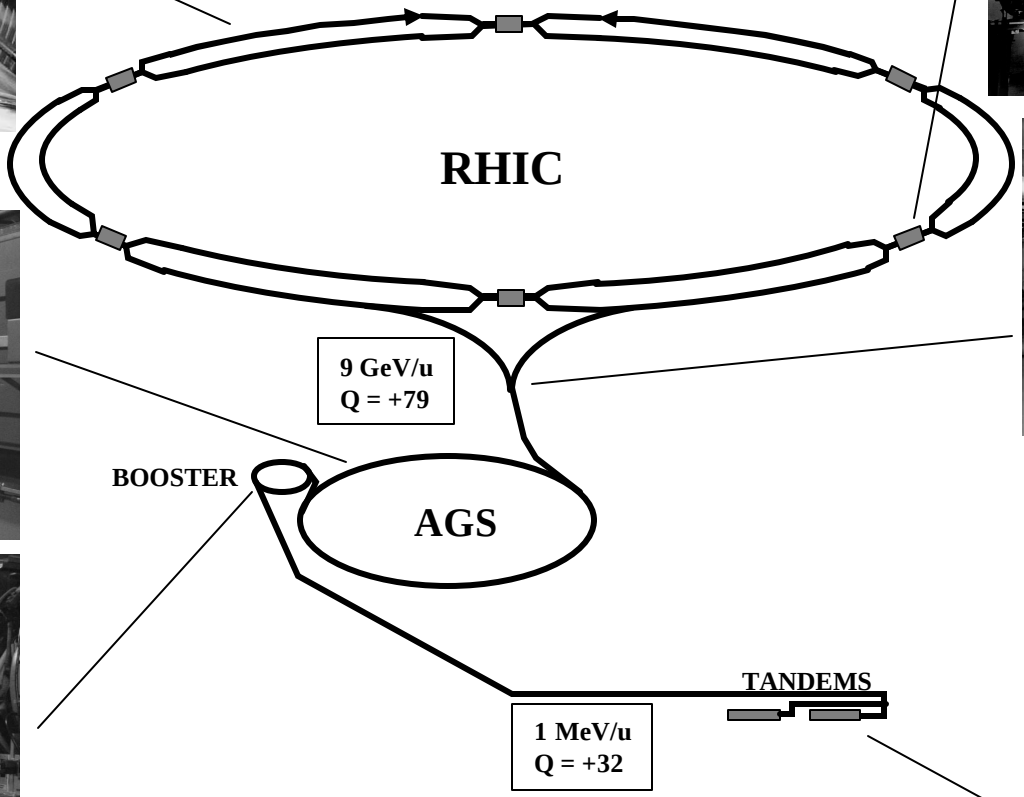
Gold Ion Collisions in RHIC



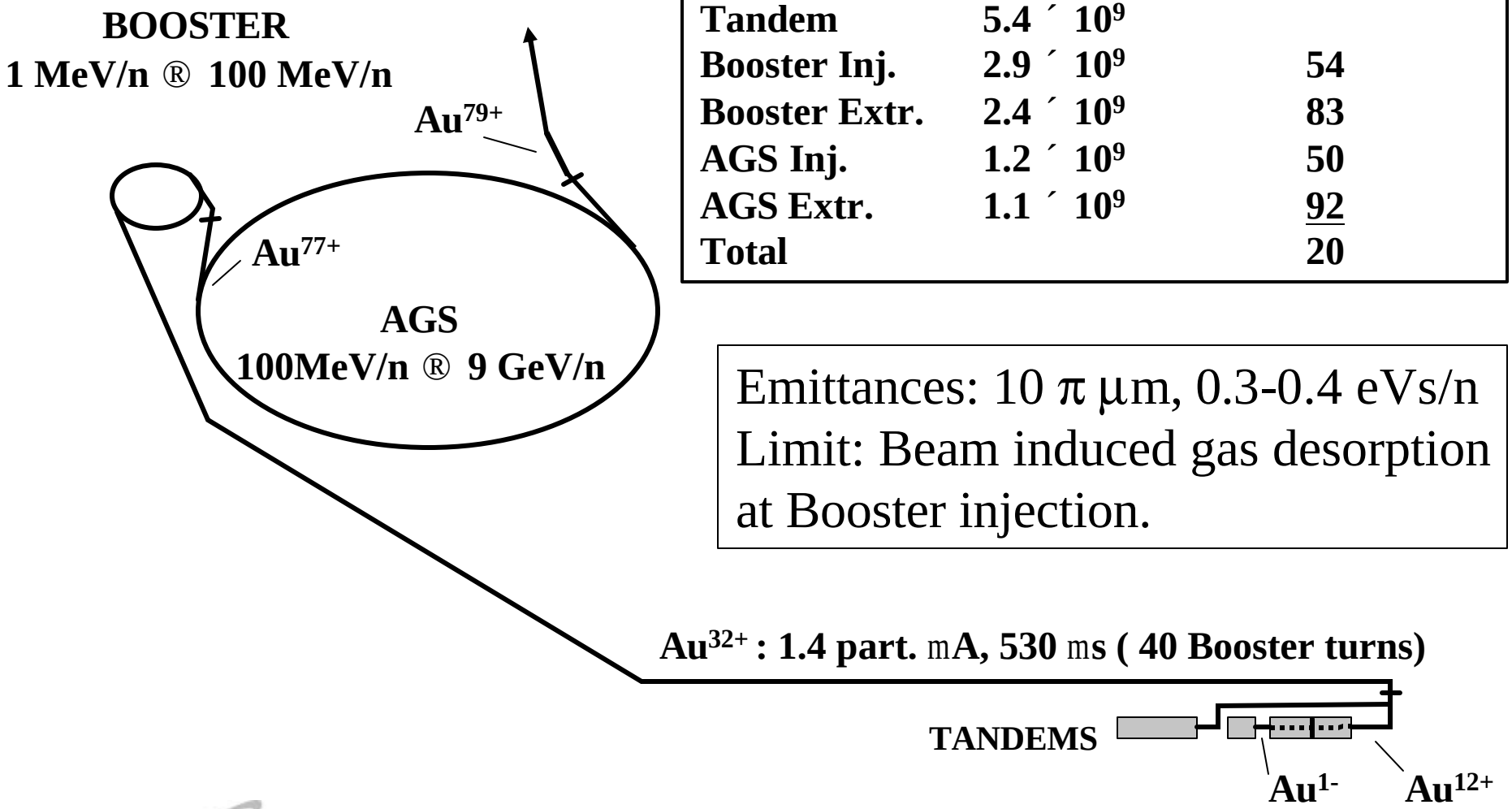




Beam Energy = 100 GeV/u
L_{ave} per IR = 2 ´ 10^{26} $cm^{-2}sec^{-1}$



Au Injector Performance



	Intensity/RHIC bunch	Efficiency[%]
Tandem	5.4×10^9	
Booster Inj.	2.9×10^9	54
Booster Extr.	2.4×10^9	83
AGS Inj.	1.2×10^9	50
AGS Extr.	1.1×10^9	92
Total		20

Emittances: 10 π μm, 0.3-0.4 eVs/n
Limit: Beam induced gas desorption at Booster injection.

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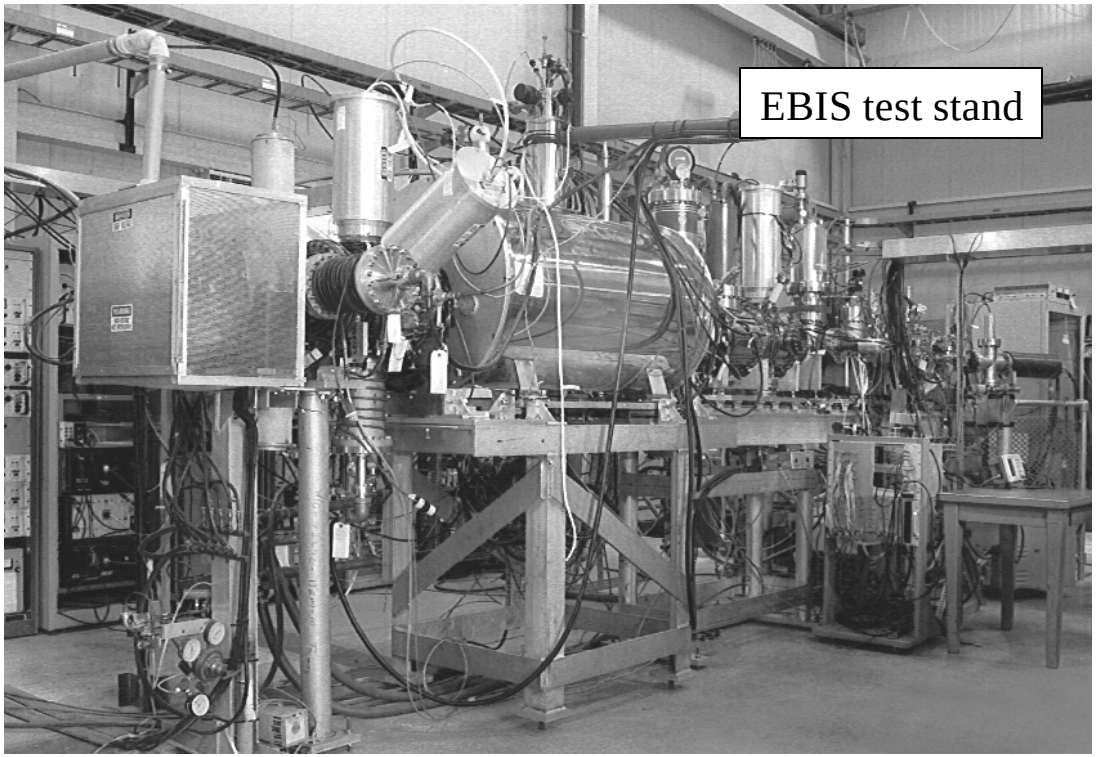
EBIS/Linac RHIC Pre-Injector

- Highly successful development of Electron Beam Ion Source (EBIS) at BNL
- EBIS allows for a reliable, low maintenance Linac-based pre-injector replacing the Tandem Van de Graaffs
- Produces beams of all ion species including Uranium and polarized He^3 (for eRHIC)



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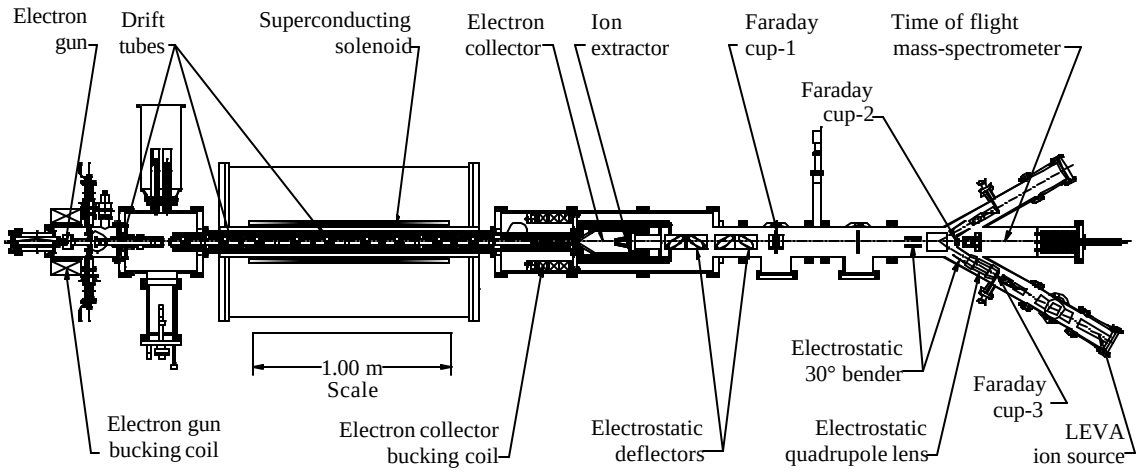
Results from Test EBIS (½ of RHIC EBIS)



	RHIC Requirements	Achieved
E-beam current	**10 A**	**10 A**
E-beam energy	**20 keV**	**20 keV**
Yield of pos. charges	**5.5 ´ 10^{11} (Au, 10 A, 1.5m)**	**3.2 ´ 10^{11} (Au, 8 A, 0.7m)**
Pulse length	**£ 40 ms**	**20 ms**
Yield of Au^{33+}	**3.4 ´ 10^{9}**	**~ 1.5 ´ 10^{9}**
Yield of U^{45+}	**2.4 ´ 10^{9}**	

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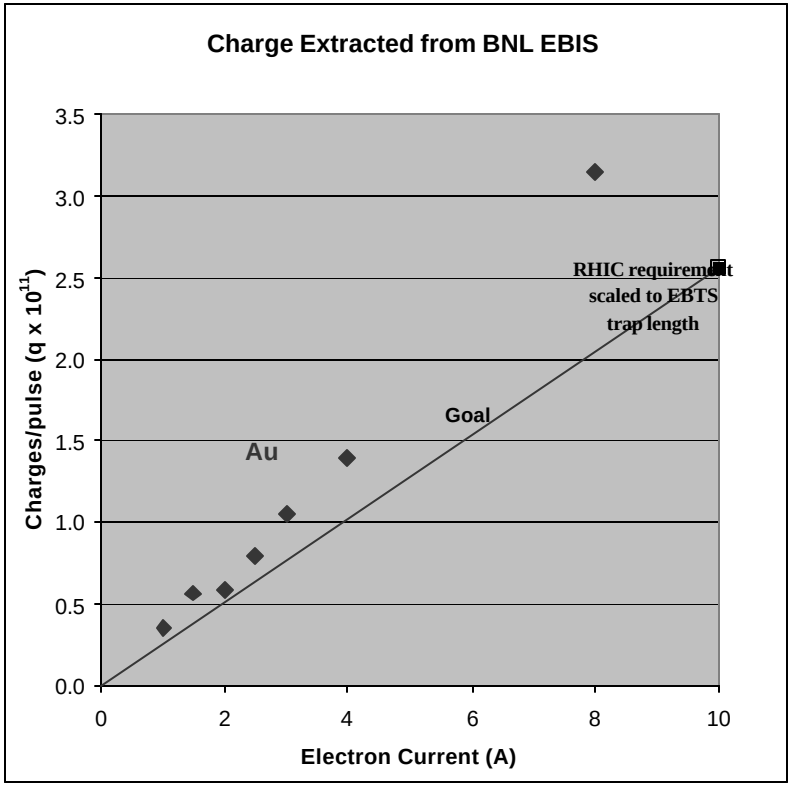
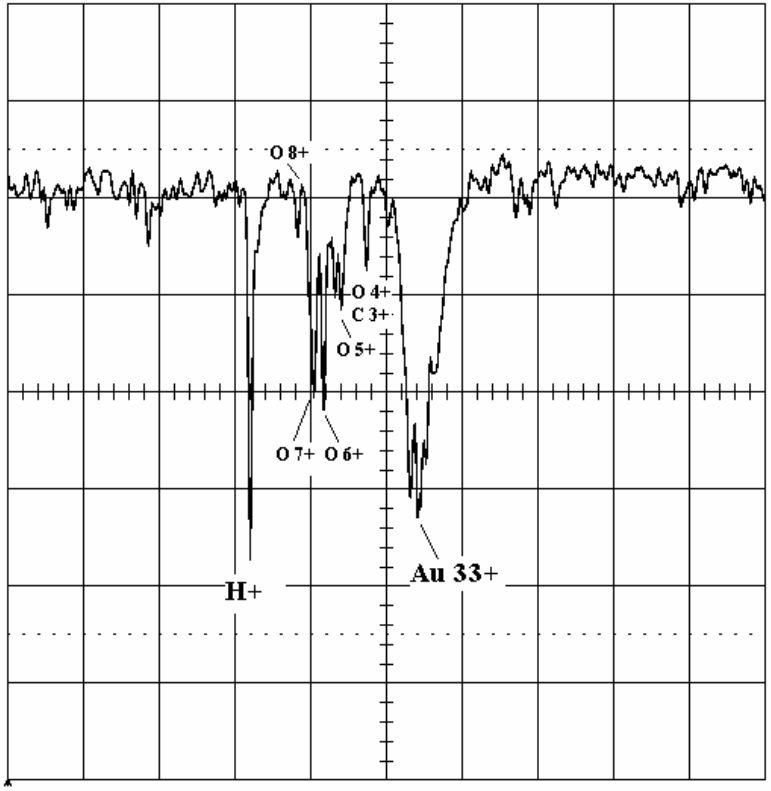
Results from Test EBIS (½ of RHIC EBIS)



Extracted gold ion yield shows more than 50% neutralization



Gold charge state with only 40 ms confinement time.

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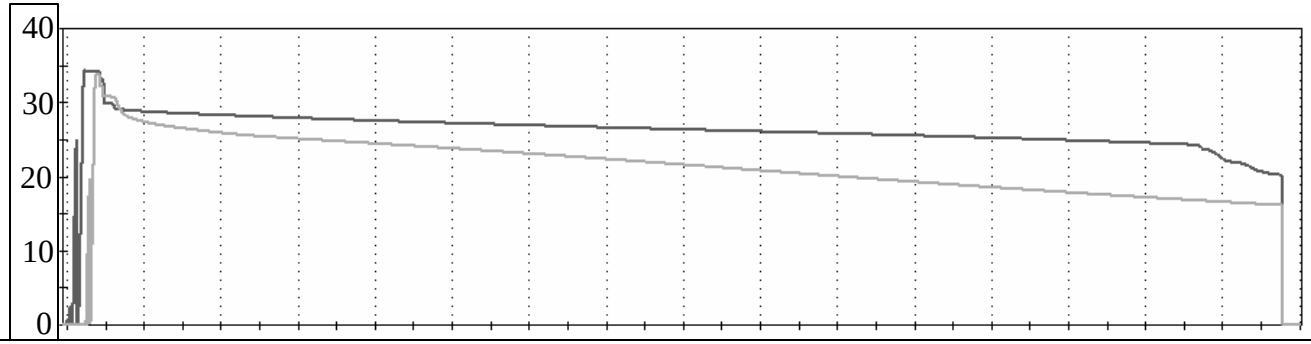
“Typical Store” # 1812

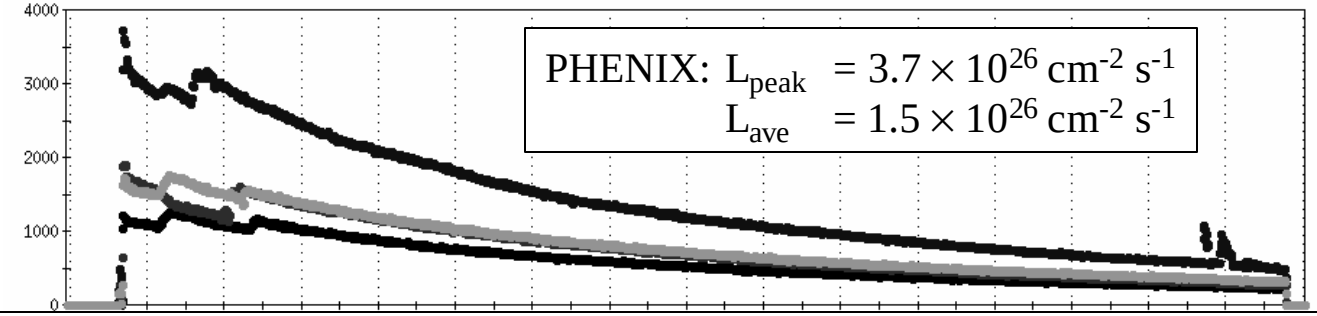
Beam currents [x10^9 ions]



Blue Beam Current

Yellow Beam Current

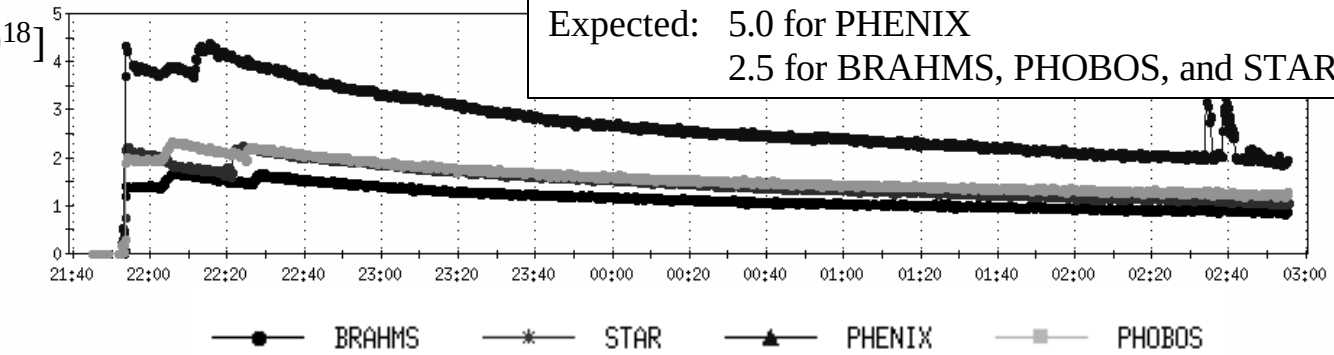
Collision rate [Hz]



PHENIX: $L_{peak} = 3.7 \times 10^{26}$ cm^{-2} s^{-1}
$L_{ave} = 1.5 \times 10^{26}$ cm^{-2} s^{-1}

~ 5 hours

Specific luminosity [Hz/10^{18}]



Expected: 5.0 for PHENIX
2.5 for BRAHMS, PHOBOS, and STAR

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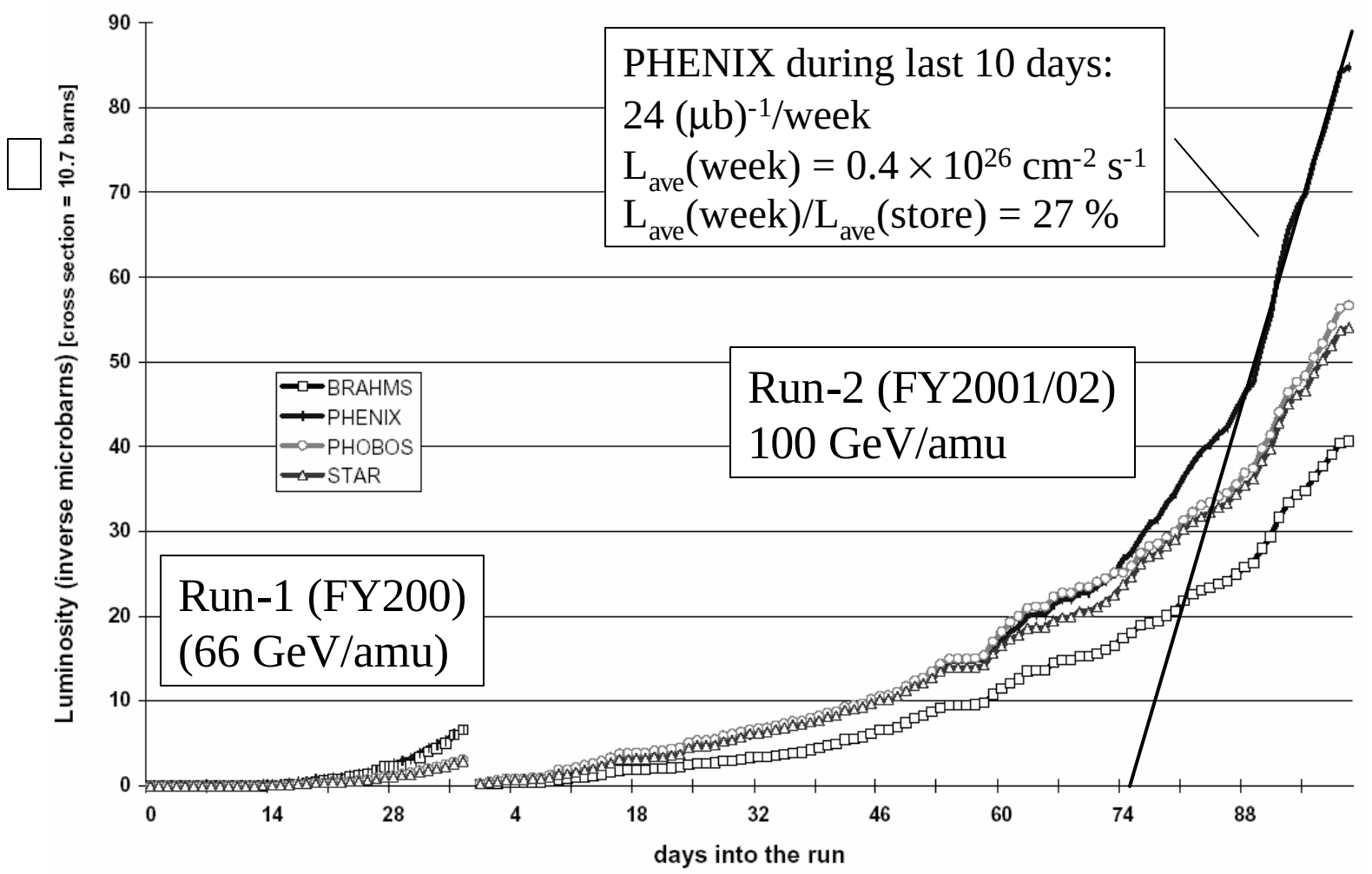
Integrated Au-Au luminosity



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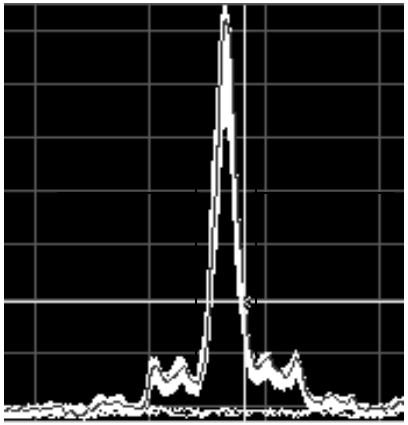
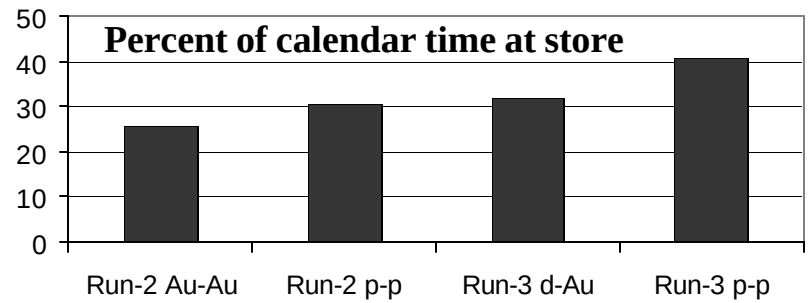
Performance summary



RHIC bunch profile

- Energy/beam: 100 GeV/nucl.
- Diamond length: σ = 20 cm



Mode	# bunches	Ions/bunch [10^9]	β^* [m]	Emittance [$\pi\mu$m]	L_{peak} [$cm^{-2}s^{-1}$]	L_{ave}(store) [$cm^{-2}s^{-1}$]	L_{ave} (week) [$week^{-1}$]
Au-Au (*) [Run-2]	55	0.7	1	15 - 40	5×10^{26}	1.5×10^{26}	24 $(\mu b)^{-1}$
d-Au (*) [Run-3]	55	110(d), 0.7(Au)	2	15	7×10^{28}	2.0×10^{28}	4.5 $(nb)^{-1}$
p↑-p↑ (*) [Run-3]	55	70	1	20 - 30	6×10^{30}	3×10^{30}	0.6 $(pb)^{-1}$
d-Au (max. goal)	56	80(d), 1(Au)	2	20	4×10^{28}	1.6×10^{28}	4 $(nb)^{-1}$
p↑-p↑ (max. goal)	112	100	1	25	16×10^{30}	10×10^{30}	2.8$(pb)^{-1}$
Au-Au RHIC design	56	1	2	15 - 40	9×10^{26}	2×10^{26}	50 $(\mu b)^{-1}$
p-p RHIC design	56	100	2	20	5×10^{30}	4×10^{30}	1.2 $(pb)^{-1}$
p↑-p↑ RHIC spin	112	200	1	20	80×10^{30}	65×10^{30}	20$(pb)^{-1}$

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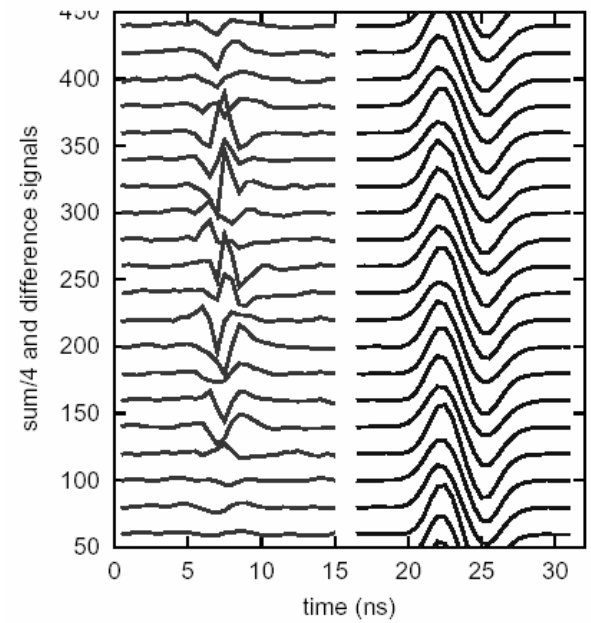
[(*) Best store or last week]

Luminosity Limitations (1)

- Injector performance (routine):
  - Au 0.7 ´ 10^9 /bunch 10 π μm 0.3 eVs
    - additional bunch merge
  - p 0.8 ´ 10^{11} /bunch 10 π μm 0.3 eVs 40%
  - p 2.0 ´ 10^{11} /bunch 20 π μm 0.5 eVs 20% (?)
    - strong AGS partial snake, thinner H^- stripping foil
- Single bunch instabilities around transition:
  - Effect of vacuum chamber impedance, electron cloud (?)
  - Au: < 0.8 ´ 10^9 ions/bunch
    - cross zero-chromaticity before transition (why?)
- Electron multi-pacting (electron cloud)
  - Total charge per ring less than ~ 10^{13} e, worse for 110 bunches
    - Solenoids, scrubbing, NEG coating, clearing electrodes (?)
- Vacuum problem due to halo scrapping / ion desorption around transition (?)
  - Total accelerated charge in both rings < 10^{13} e
    - More baking, scrubbing, NEG coating



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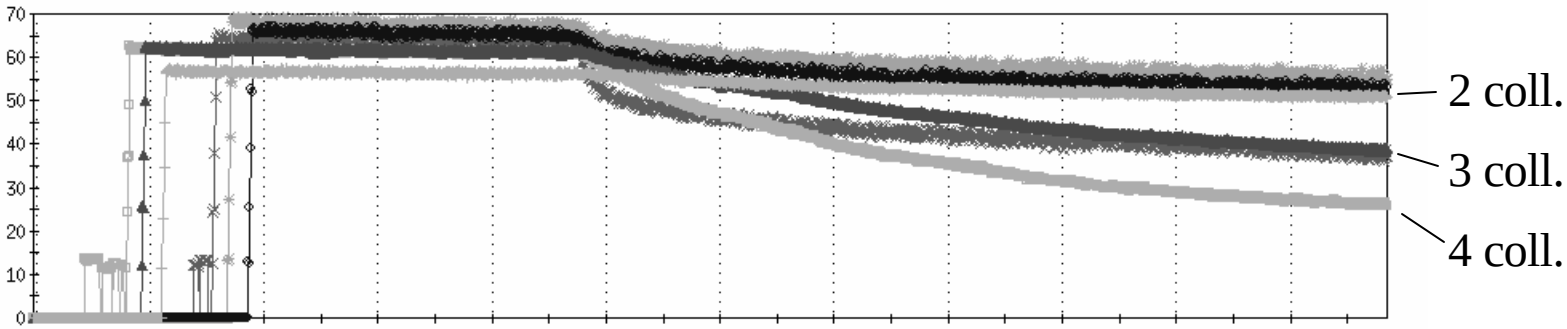
Luminosity Limitations (2)

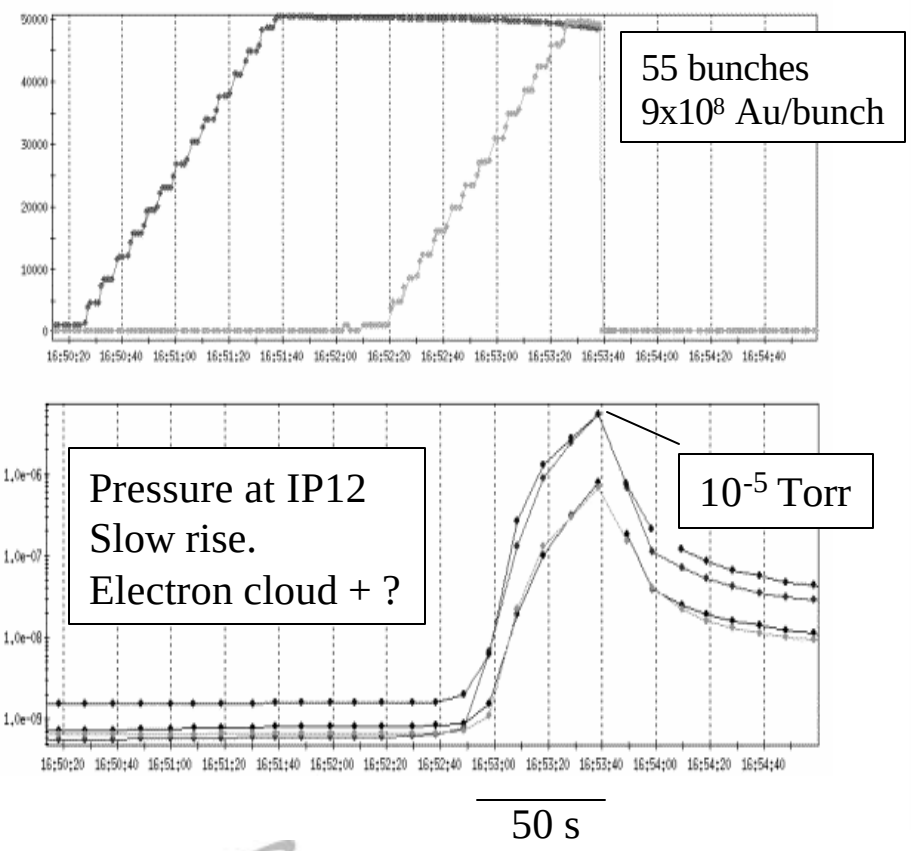
- Beam-beam tune shift and spread
  - First strong-strong hadron collider (after ISR)
  - Limits high luminosity pp operation to two IRs
    - Non-linear corrections, better working point

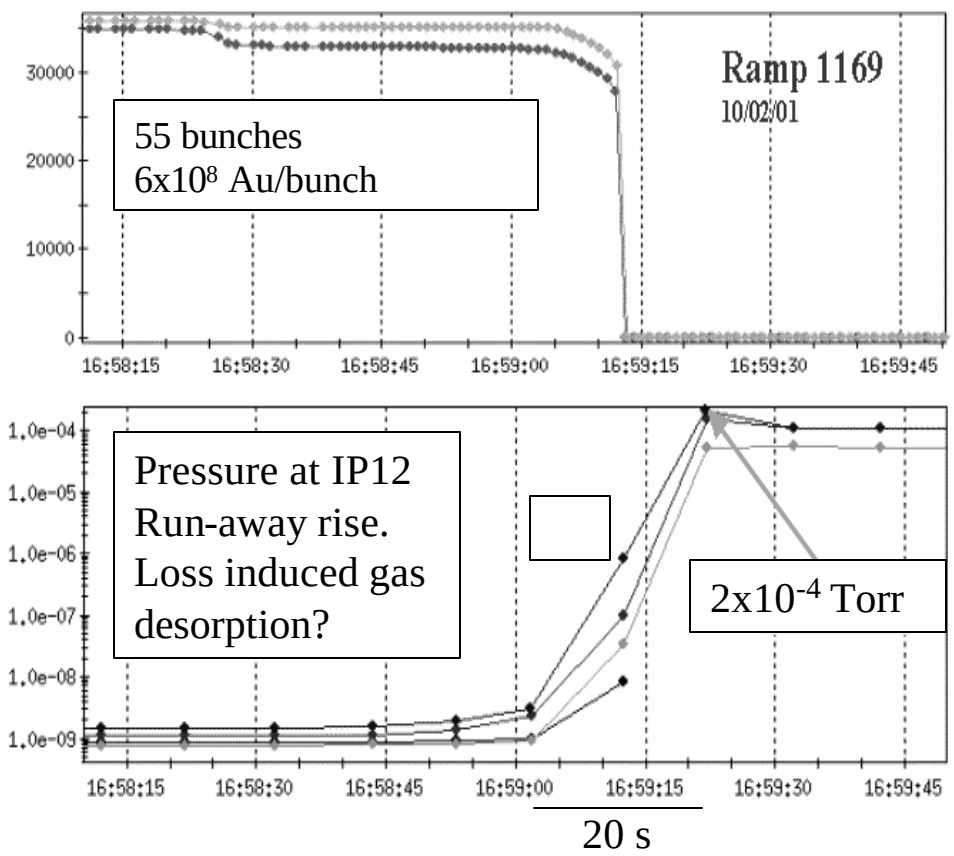


- Intra-Beam Scattering (IBS)
  - Transverse and longitudinal emittance growth
  - Eventually will need electron cooling

Vacuum break-down

- Mainly in warm sections that didn't have bake-out; worse with 110 bunches/ring
- Ion desorption, electron desorption, electron multi-pacting, electron cloud
- Installed electron detectors in IP12 and IP2 and solenoids for electron suppression in IP12.
- "scrubbing" with beam, NEG coated vacuum chambers





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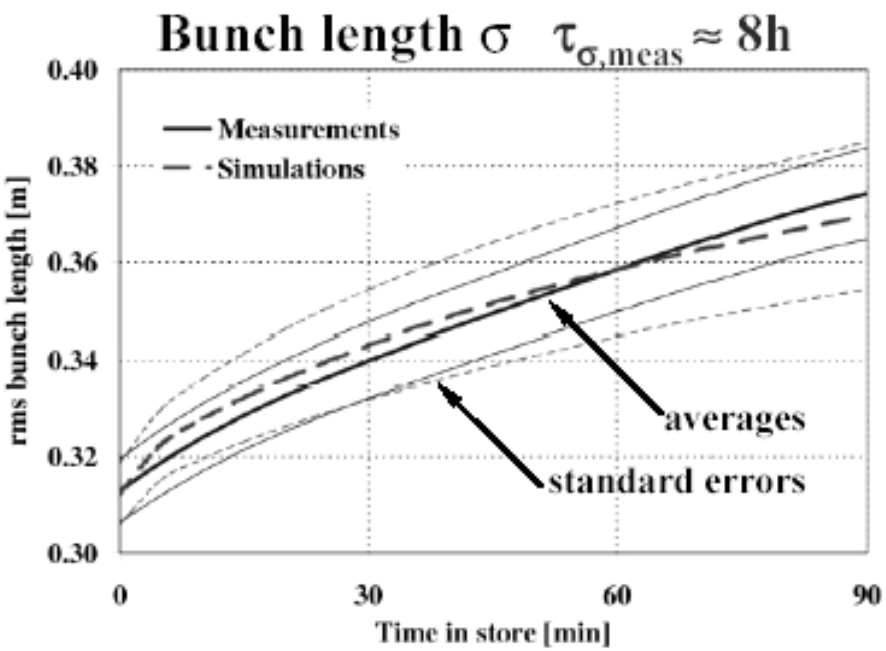
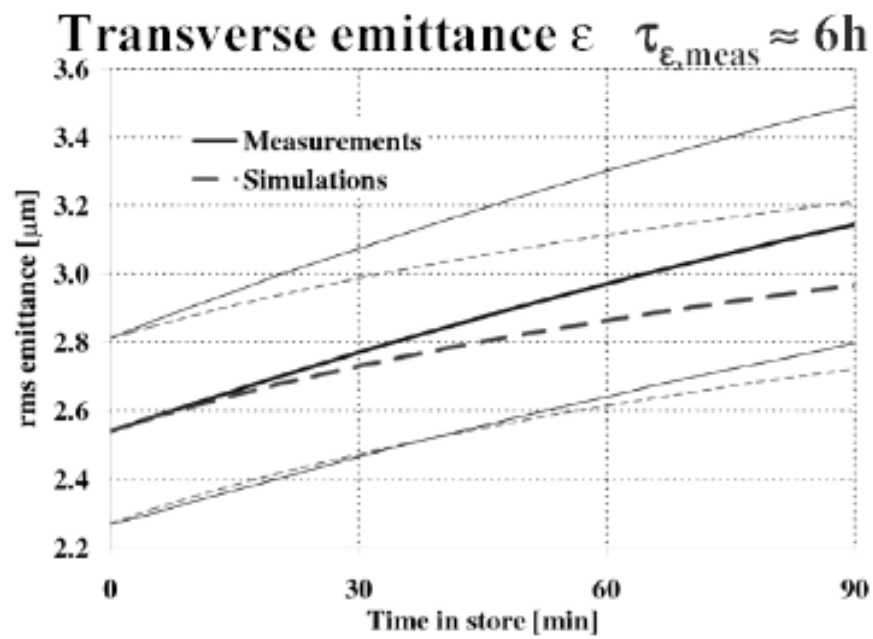
Machine goal for next 5-years

- **Enhanced RHIC luminosity (112 bunches, b* = 1m):**
- **Au – Au: 8 ´ 10^{26} cm^{-2} s^{-1} (100 GeV/nucleon)**
- **For protons also 2 ´ 10^{11} protons/bunch (no IBS):**
- **p - – p - : 6 ´ 10^{31} cm^{-2} s^{-1}; 70 % polarization (100 GeV)**
  1.5 ´ 10^{32} cm^{-2} s^{-1}; 70 % polarization (250 GeV)
  (luminosity averaged over store delivered to 2 IRs)

→ Vacuum problems in RHIC need to be solved !

Intra-Beam Scattering (IBS) in RHIC

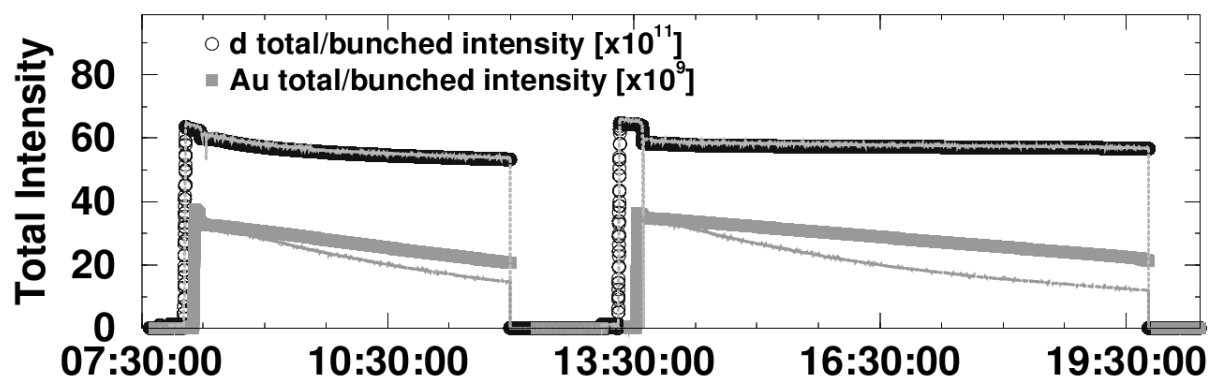




Longitudinal and transverse emittance growth agrees well with model

Some additional source of transverse emittance growth

Deuteron and gold beams are different because of IBS



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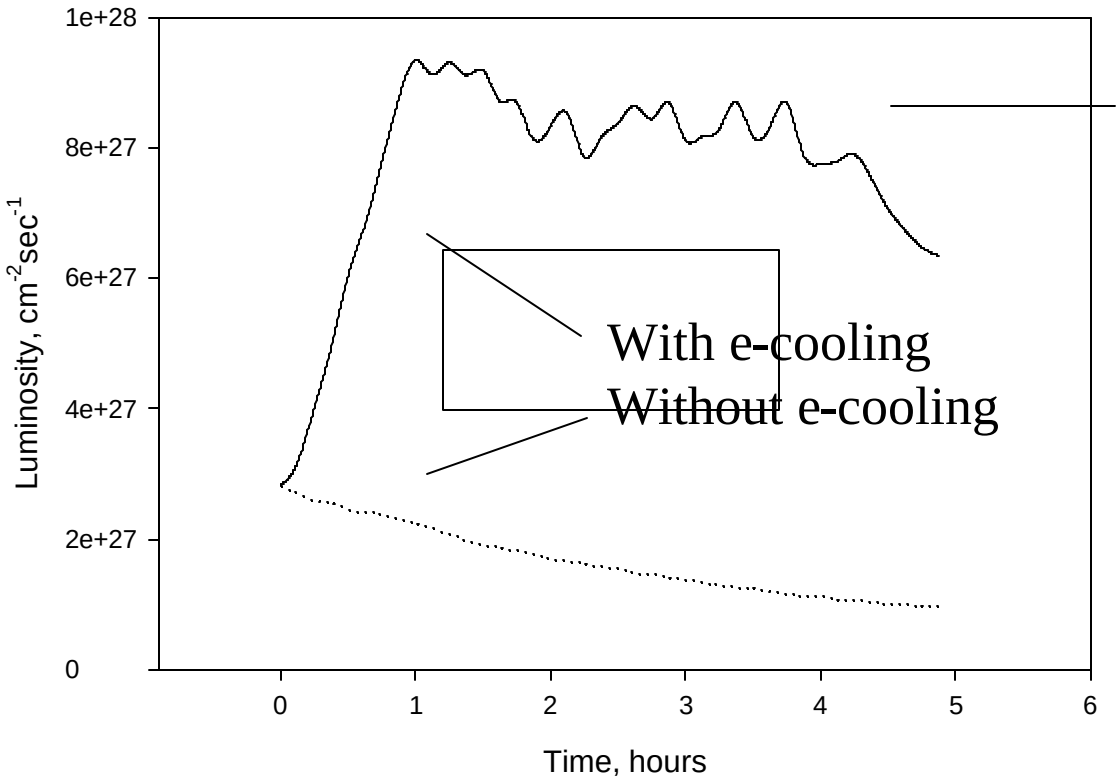
RHIC Luminosity Upgrade

- RHIC luminosity is limited by intra-beam scattering → beam cooling at full energy! With cooling RHIC luminosity could be increased ten times.

- Bunched electron beam requirements for 100 GeV/u gold beams:
  E = 54 MeV, <I> ~ 100 mA, electron beam power: ~ 5 MW!
- Requires high brightness, high power, energy recovering superconducting linac, as demonstrated by JLab for IR FEL. (50 MeV, 5 mA)
- Electron cooling with bunched, high energy electron beam
- Use of high p_t electrons to avoid recombination of e^- and Au^{79+}

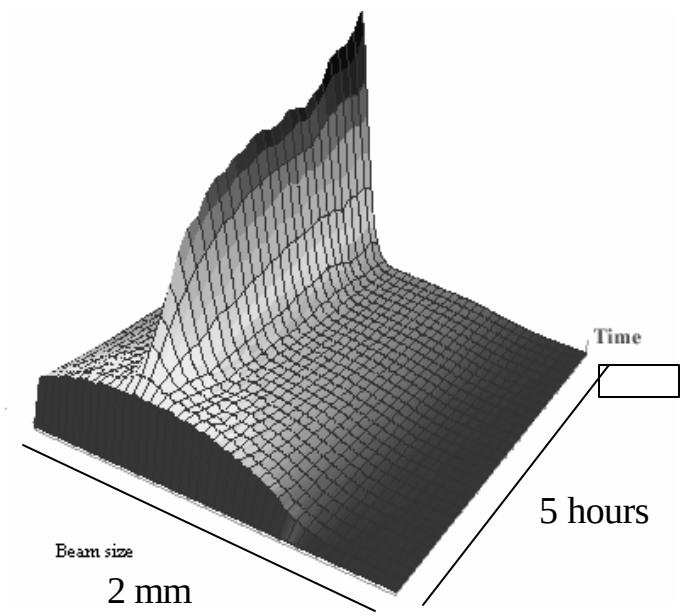
- Maintains present bunch spacing (~ 100 ns) and available IR length
- Increased luminosity for pp and other species
- Longitudinal cooling possibly gives shorter diamond length

RHIC Luminosity with and without Cooling



Luminosity leveling through continuous cooling and beta squeeze
Store length limited by "burn-off"

Transverse beam profile during store



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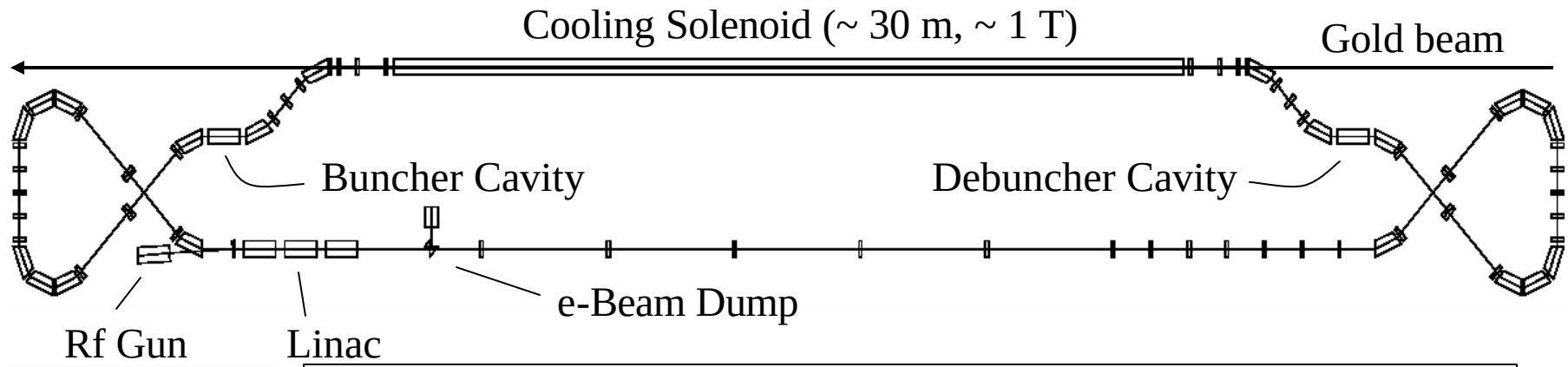
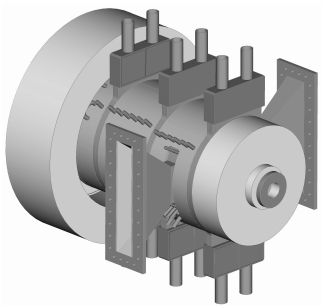
RHIC Electron Cooler R&D

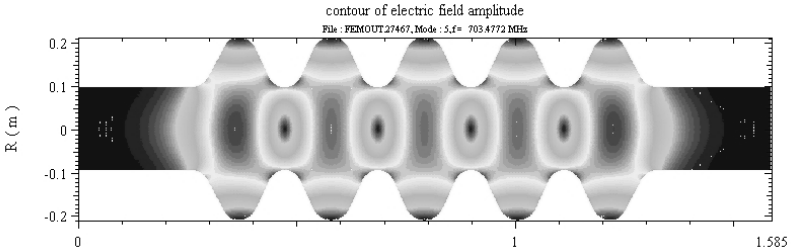


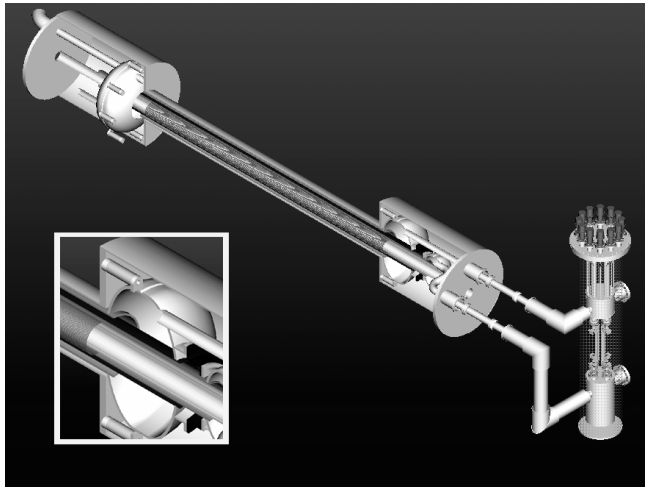


Demonstrate 10 nC, 100 – 300 mA CW rf photo-cathode electron gun:
High power, 700 MHz 2.5 cell cavity (collab. with LANL, AES)

Demonstrate high precision (10 ppm) solenoid

Develop CW s.c. cavity for high intensity beams:
Large bore, 700 MHz cavity with ferrite HOM dampers
and high beam break-up threshold (collab. with Jlab, AES)





Bunched Beam Stochastic Cooling at RHIC

- No coherent signal for Au beams!
  (observed coherent signal with proton beams)
- Microwave stochastic cooling (~ 5 GHz) may work for longitudinal cooling and avoid beam debunching during store.
- Halo cooling in combination with e-cooling.

- Optical stochastic cooling (~ 30 THz) of Au beams has great potential for the long term future.
- Proof-of-principle R&D proceeding

Summary

- Successful operation of RHIC with 100 GeV/n beams in three modes: (at very similar nucleon pair luminosity)
  - Gold – gold collisions, peak luminosity = 5×10^{26} cm^{-2} s^{-1}
  - Deuteron – gold collsions, peak luminosity = 7×10^{28} cm^{-2} s^{-1}
  - Polarized proton collsions, peak luminosity = 6×10^{30} cm^{-2} s^{-1}

- Further luminosity improvements requires resolution of vacuum problems

- RHIC luminosity upgrade ($\times$ 10) using full energy electron cooling